

Electronic applications of semiconducting polymers

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A review of the basic properties and conduction mechanism in semiconducting polymers has been presented. Results of our investigations on the semiconducting polymers, polypyrrole and polyaniline, have been discussed. A promising vacuum-deposited polymeric semiconducting device fabrication technique has been detailed with its possible application in light emitting and photovoltaic devices. The use of polymeric semiconductors in surface mount technology and VLSI has also been discussed.

Introduction

Conjugated polymers are the new class of materials used for fabrication of solid state devices¹⁻¹⁰. Comparison of semiconducting polymers with conventional semiconductors is not straight forward and simple. Electrical conduction in polymers may arise due to a variety of phenomena operating in polymers that may differ from the ones in conventional semiconductors. However, the resultant electronic effects in the polymeric semiconductors appear to be similar to those in inorganics. Polymeric semiconductors have several advantages over the conventional ones, e.g., ease of processing, cost effectiveness, light-weight, abundance of raw material, and most important, sophisticated technology of single crystal growth is not required. The disadvantages on the other hand, are the lack of complete understanding of the electrical conduction mechanism and the exact labeling of the conduction species. Due to these shortcomings the actual device fabrication and application to technology using semiconducting polymers is still in its infancy.

Semiconducting polymers find application in fabrication of solid state active device elements, photovoltaics, photocells, electrochromic and memory devices and battery electrode applications in areas as diverse as space, civil, military, photonic, opto-electronics and communications¹¹⁻¹⁷.

Other prospective applications of conducting polymers include electrochromic displays, packaging materials, capacitors, cable shielding, controlled medicine release systems, electro-robotics, etc. All these applications require the polymers in the form of a device that can be used as an active

element. Hence the materials requirements for specific applications become quite stringent. Advancement in solid state device fabrication technology thus requires improvement in three aspects, viz., materials, contacts and encapsulation. These may be achieved by improvements in the synthesis, processing and precise control of dopants and optimising process control parameters. New information about their structure and properties make polypyrrole, polyaniline and polythiophene promising materials for device fabrication. These polymers can be fabricated to conduct electricity across the whole length of the conjugated molecular chain. Structurally, the polymers are not like inorganics which can be assumed to be either crystalline or polycrystalline, and their physical properties cannot be exactly explained on the basis of knowledge available for inorganics. They behave like amorphous solids and the simple band theory fails to explain the conduction of electricity in polymers. For any electronic device application, the two essential parameters are the knowledge of conduction mechanism and the properties of the interface with other materials. There are no electrons or holes (as in inorganics) to help conduction, but more complex species, which do not have spin (e.g. in polypyrrole).

To explain the conduction in polymers we have to assume the validity of the band theory of solids for polymers to the nearest approximation. When electron is removed from the top of the valence band (by oxidation) of the conjugated polymer, a vacancy (a radical cation) equivalent to a hole is created that does not delocalize completely, but is

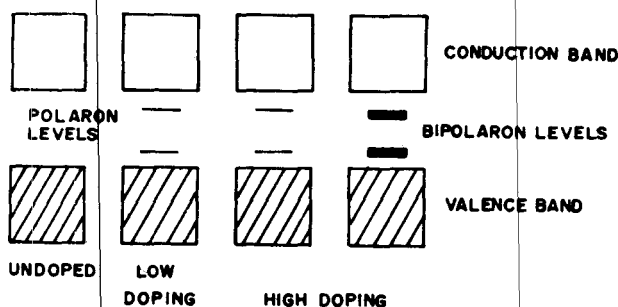


Fig. 1—Energy band diagram and defect levels for polarons and bipolarons in undoped, lightly doped and heavily doped conducting polymers

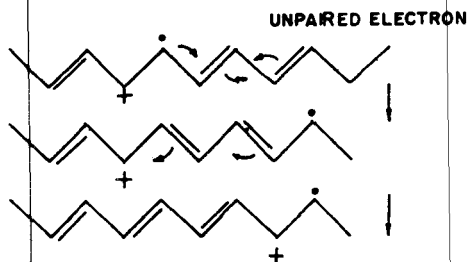


Fig. 2—Propagation of polaron through a conjugated polymer chain by shifting of double bonds (alternation) that gives rise to electrical conduction

delocalized only over a few monomeric units deforming the polymeric structure. This partially delocalized radical cation is called a polaron and has a spin $1/2$. The energy level associated with this radical cation represents a destabilized bonding orbital. It has an energy higher than the valence band, (to the nearest band theory approximation) and lies in the band gap. This is similar to band tailing in amorphous chalcogenides. Now if another electron is removed from the already oxidized polymer, it can create another polaron or a bipolaron. Low level doping gives rise to polarons and high doping results in the formation of bipolarons. Figure 1 shows the energy levels in polymers as a result of doping. The polarons and bipolarons are mobile and under the influence of electric field, can move along the polymer chain, from one chain to another and from one granule to another, exactly in the manner electrons and holes do in inorganics¹⁸⁻²³.

Theoretical calculations show that the effective mass and mobility of these species is quite different from those of the electrons and holes in inorganics. The polarons and bipolarons move along the chain through the rearrangement of double and single bonds (Fig. 2). Most of the electrical and optical phenomena in conjugated polymers are thought to arise due to these pola-

rons and bipolarons. In addition, these properties can be modified by suitable doping during the synthesis. It is possible to prepare polymeric materials like polypyrrole, polyaniline and polythiophene having semiconducting properties by suitable processing and requisite doping.

Preparation of semiconducting polymers

Most of the semiconducting polymers, polypyrrole, polyaniline and polythiophene are prepared by electrochemical and chemical methods.

Polypyrrole—Polypyrrole films are usually prepared by electrochemical methods with high purity chemicals¹. Polypyrrole deposition is carried out under isothermal conditions (at about 5°C) in a single compartment cell with three electrodes. The films are formed on the conducting electrode (usually an indium tin oxide coated glass) of the electrochemical cell. The cathode consists of a platinum foil and the electrochemical cell solution contains 0.1M pyrrole monomer and 0.1M tetraethylammonium tetrafluoroborate and propylene carbonate as solvent. The electrochemical deposition is carried out in an inert atmosphere at current densities of the order of $2\text{-}3\text{ A/cm}^2$ at 15 V . Self supporting films of various thickness can be obtained by varying the deposition time. The conductivity of these films varies from $5\text{-}15\text{ S cm}^{-1}$. Deposition of the film occurs as a result of pyrrole oxidation.

The doping and oxidation of polypyrrole occur during the electrochemical polymerization process (Fig. 3). These pyrrole units have positive charge, which is balanced by a variety of dopant anions. Undoping of the film can be carried out by treating with NH_3 or other similar chemicals.

Polyaniline—Polyaniline is usually prepared by redox polymerization of aniline using ammonium persulphate, $(\text{NH}_4)_2\text{S}_2\text{O}_8$, as an oxidant. Dis-

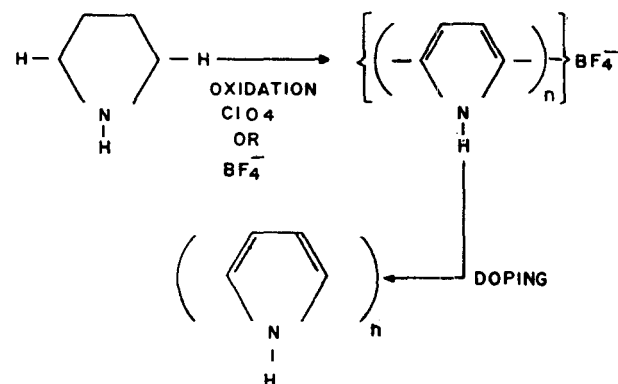
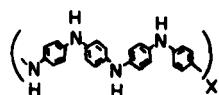


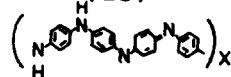
Fig. 3—Electrochemical formation-oxidation-doping of polypyrrole

LEUCOEMERALDINE BASE (LB)

FULLY REDUCED
INSULATOR

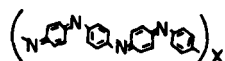
$$[I-Y] = 0$$

EMERALDINE BASE (EB)

HALF REDUCED-HALF OXIDISED
WEAK INSULATOR

$$[I-Y] = 0.5$$

PERNIGRANILINE BASE (PNB)



FULLY OXIDISED

$$[I-Y] = 1.0$$

CONDUCTING EMERALDINE SALT (ES)

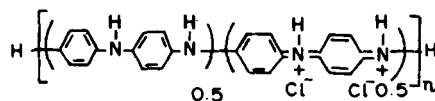
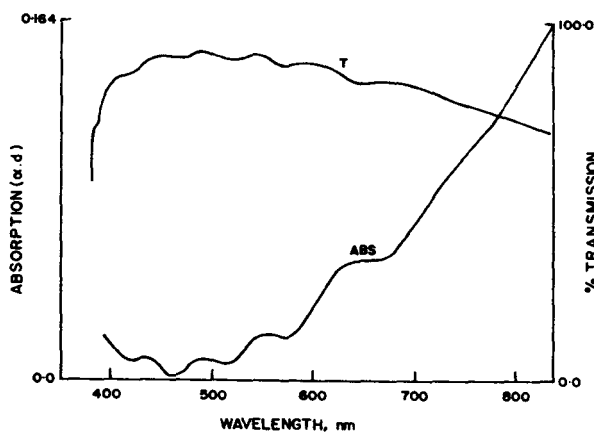
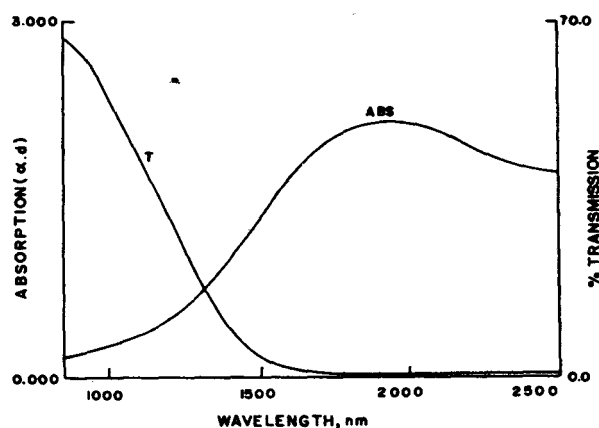


Fig. 4—Four forms of polyaniline

Fig. 5—Variation of optical absorption and transmission in the wavelength range 300-900 nm for BF_4^- doped polypyrrole filmsFig. 6—Variation of optical absorption and transmission in the wavelength range 900-2600 nm for BF_4^- doped polypyrrole films

tiled aniline, (0.2M) is dissolved in 300 ml of precooled HCl (1.0M) solution, maintained at 0.5°C. A calculated amount of ammonium perdisulphate (0.05M) dissolved in 200 ml of HCl (1M), precooled to 0.5°C, is added to the above solution. The dark green precipitate resulting from this reaction is washed with HCl (1M) until the green colour disappears. This precipitate is

further extracted with tetrahydrofuran and NMP solution by Soxhlet extraction and dried to yield the emeraldine salt. Emeraldine base can be obtained by heating the emeraldine salt with ammonia solution. The powder so obtained can be used for device fabrication.

Polyaniline exists in four different forms. These four structurally transformed forms of polyaniline

are achieved through the protonation and doping of the base form. These forms have a wide range of electrical conductivity—from insulating to conducting. Conductivity of the order of 10 S/cm can be obtained for the conducting form^{2,3} (Fig. 4).

Optical characterization

The optical characterization of the semiconducting polymers is usually carried out by either preparing a transparent thin film or making a solution of the polymer transparent to the incident radiation. IR spectroscopy identifies and confirms the structure and characteristics of the polymer, while the UV-visible spectra give the energy band gap and defect states. The transmission and absorption peaks correspond to various levels in the energy band gap (Figs 5 & 6).

The energy band gap of polymer thin films is given by the following equation:

$$\alpha \cdot d = (h\nu - E_g)^{1/2}$$

where $\alpha \cdot d$ is optical absorption, E_g is energy band gap, and $h\nu$ is incident photon energy.

From the above, the optical absorption edge of polypyrrole films is estimated to be about 2.7 eV and the energy band gap at 3.0 eV (Fig. 7).

The FTIR spectra of HCl doped polyaniline is

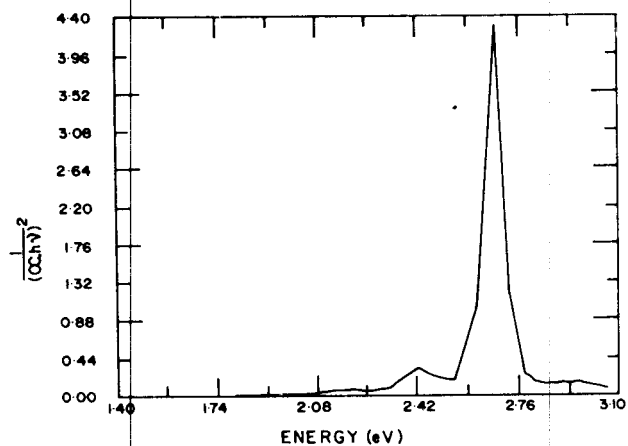


Fig. 7—Plot of $(\alpha \cdot hv)^2$ versus energy for BF_4^- doped polypyrrole films

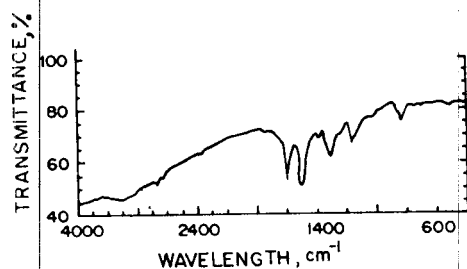


Fig. 8—FTIR spectra of HCl doped polyaniline

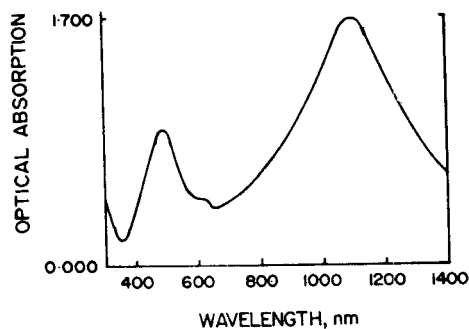


Fig. 9—Variation of optical absorption of HCl-doped polyaniline with wavelength

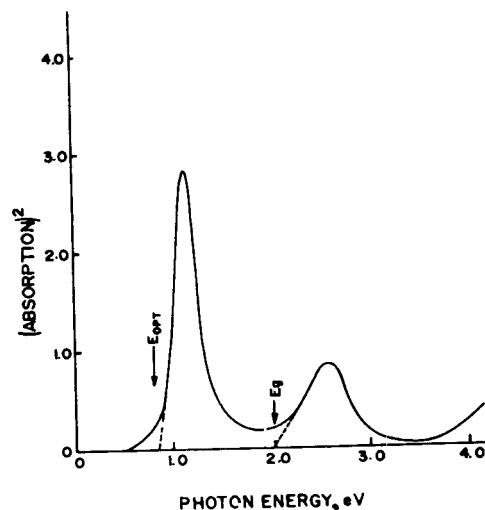


Fig. 10—Variation of optical absorption with photon energy for polyaniline

shown in Fig. 8. The peaks correspond to the various molecular and side chain characteristics of the polyaniline structure. Figure 9 shows the variation of optical absorption of HCl doped polyaniline with wavelength in the range 400-1000 nm. From this, the band gap of polyaniline has been estimated to be ~ 2.1 eV (Fig. 10).

Electrical characterization

For electronic applications, important characterization includes electrical conductivity and the interface behaviour of the polymer with various materials. The semiconducting polymers are p-type and except for polyacetylene it has not been possible to prepare the n-type for polymers like polypyrrole, polyaniline and polythiophene. It is hence not possible to prepare a p-n junction for device fabrication. The alternative is to fabricate a heterojunction of the polymer (assumed to behave like a p-type solid) with other material, e.g., a metal or a semiconductor of n-type. When a polymer

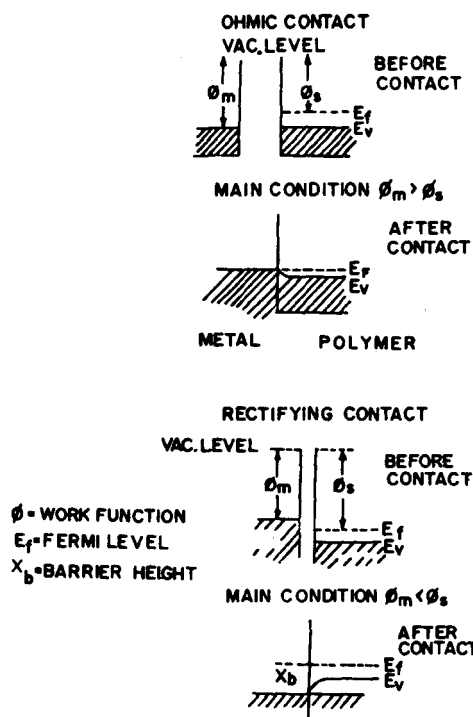


Fig. 11—Energy band scheme for metal/polymeric semiconductor contacts

is brought in electronic contact with a metal, an exchange of positive and negative charges takes place between the two. An electronic interface subsequently builds up at the junction having a depletion region in the polymer. The heterojunction interface behaviour of the metal/polymer contact is revealed by the characteristics of the interface, the current-voltage characteristics, and the capacitance-voltage characteristics. The energy band scheme for such contacts is shown in Fig. 11. Three type of junctions are possible: ohmic contact, which allows free flow of charges from the polymer to metal and vice versa, rectifying contact, which allows only unidirectional flow of charges, and, blocking contact, allowing no injection or extraction of charges from the polymer.

It has been established that the metals having a work function (ϕ_m) greater than that of the polymer (ϕ_s) make an ohmic contact and the metals with work function ϕ_m less than that of the polymer, ϕ_s , make an injecting or rectifying junction. The current through these heterojunctions is mainly thermionic emission controlled and can be explained on the basis of theories for Schottky emission.

The V - I characteristics of the polypyrrole film with various metals is shown in Fig. 12. It can be seen that the current-voltage characteristics of

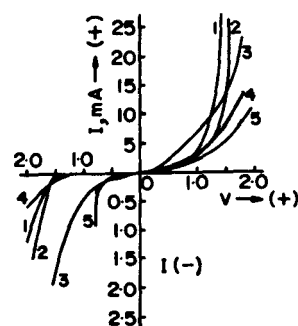


Fig. 12— V - I characteristics for polypyrrole film with various metals. [1, In (thickness 3μ); 2, Sb (thickness 3μ), 3, Ti (thickness 3μ), 4, Al (thickness 3μ); 5, Sn (thickness 10μ)]

Table 1—Electronic parameters for metal/polypyrrole junctions

Metal	Work function ϕ_m (eV)	Rectification ratio	Ideality factor (n)	Barrier height x_b (V)
Ti	4.09	10	10.64	.50
In	4.12	28	10.80	.53
Al	4.28	50	11.11	.51
Sn	4.42	30	10.45	.52

polypyrrole are quite similar to those of inorganic solids. A blocking of charges takes place at the metal/polymer interface, creating a barrier. After a certain voltage, the barrier is crossed. The current-voltage characteristics for such a junction can be explained by the Schottky relation for thermionic emission.

The current density, J , across the junction is given by the equation:

$$J = J_0 \exp\left(\frac{eV}{nkT}\right)$$

and the reverse saturation current, J_0 , is given by the equation:

$$J_0 = A^* T^2 \exp\left(\frac{-e x_b}{kT}\right)$$

where e is electronic charge, V is applied voltage, n is ideality factor, T is temperature, k is Boltzmann constant, and, A^* = Richardson constant.

The electronic parameters mentioned above are the deciding factors for the device quality of the polymer. The electronic parameters for polypyrrole films are given in Table 1. It can be seen that the ideality factor (n) for the metal/polypyrrole junction is quite high and not suitable for device

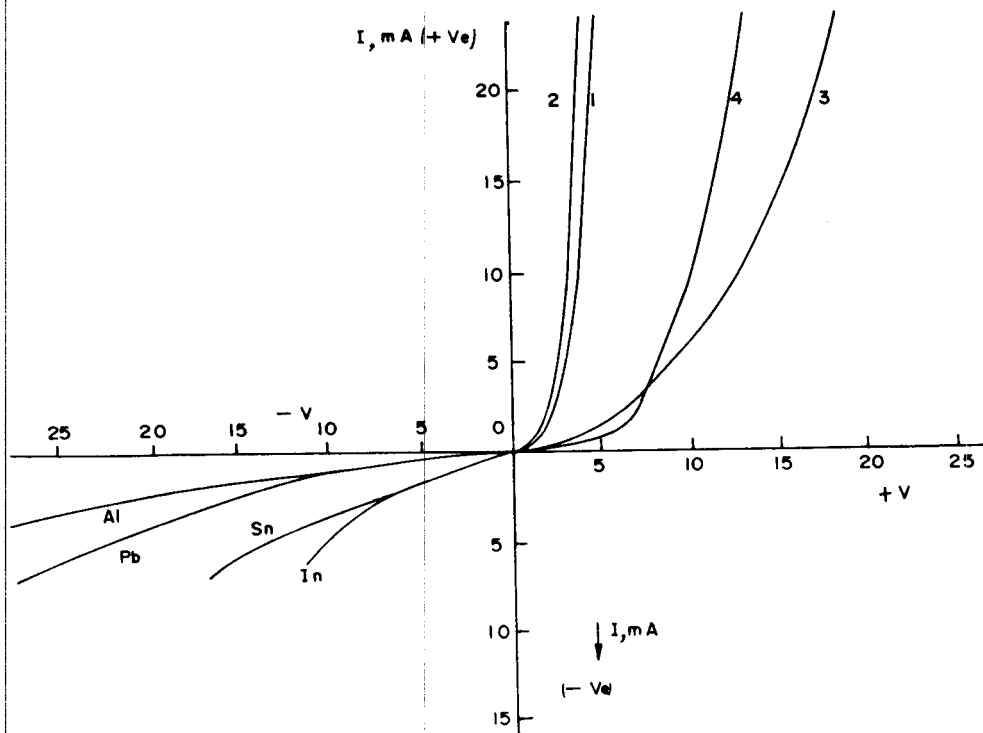


Fig. 13— V - I characteristics of metal/polyaniline junctions with various metals

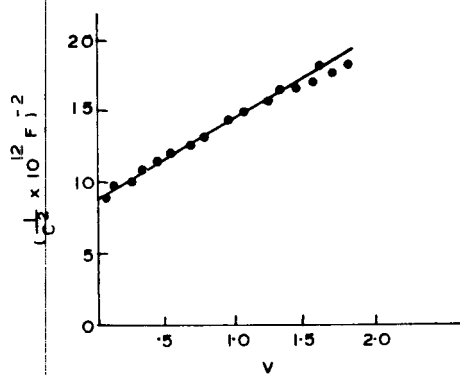


Fig. 14— C - V plot for polyaniline

fabrication. For an ideal device n should be close to 1.02.

Polyaniline appears to be a better polymer for this purpose. The V - I characteristics for various metal/polyaniline junctions are shown in Fig. 13. The V - I characteristics for metal/polymer junction follow a pattern similar to that for polypyrrole. The various electronic parameters estimated for the metal/polyaniline junction performance are summarised in Table 2.

Similarly, the work function of polypyrrole and polyaniline have been estimated to be 4.1 and 4.28 eV respectively.

The capacitance-voltage characteristics for

Table 2—Electronic parameters for metal/polyaniline junctions

Metal	Work function ϕ_m (eV)	Barrier height x_b (V)	Ideality factor η
In	4.12	0.4	1.9
Sn	4.11	0.4	4.9
Pb	4.02	0.5	6.9
Al	3.74	0.4	2.8
Ag	4.28	ohmic	—

metal/polyaniline heterojunction are shown in Fig. 14. The estimation of carrier concentration which is a measure of dopant concentration in the polymer is given by:

$$N = \frac{2A^{-2}}{e\epsilon\epsilon_0 \left[\frac{dV}{d(1/C^2)} \right]}$$

where A is area of the interface, ϵ is permittivity of the polymer, ϵ_0 is the free space permittivity, and C is junction capacitance.

The carrier concentration in the polymer plays a major role in deciding its electrical conductivity and device quality. For polyaniline the carrier concentration is of the order of 10^{17} cm^{-3} .

Vacuum deposition of polymeric thin films

Semiconducting polymers are prepared by wet chemical and electrochemical methods. While modifications of the optical and electrical properties are possible either during materials processing or later, they are not very accurate. A thin film device made of semiconductor polymer is always preferred for any technological application and also for the study of device characteristics, electrical conduction and electronic parameters in various configurations. Fabrication of a metal-semiconducting polymer junction is important for such studies and preferred for solid state device technology due to its clean processing conditions and specific process control. A vacuum deposited metal-polymer configuration is the best form of such a specimen. This process eliminates the wet chemical steps in device fabrication.

The fabrication of metal-polymer heterojunction, using various metals by an all vacuum deposition process has been developed by us^{4,24}. It has been observed that the polymer structure remains intact in the thin films formed by vacuum evaporation. In the metal-polyaniline-metal configuration, the metals having a work function lower than that of the polymer (p-type polyaniline) make a rectifying junction and those with a work function higher than that of polyaniline make an ohmic contact. The junction characteristics of such configurations have been studied, and electronic parameters like barrier height and ideality factor have been estimated^{4,24}.

The films are prepared on glass substrate by evaporating the emeraldine base powder under vacuum (10^{-6} mm Hg). Various metals are used for making the electrical sandwich structure metal/polymer/metal configurations. The FTIR spectra of such vacuum deposited polyaniline films are shown in Fig. 15 with the UV-vis optical absorption spectra (inset) for estimation of the en-

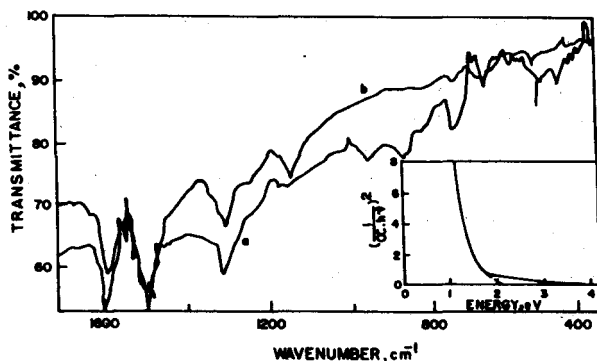


Fig. 15—FTIR spectra of vacuum deposited polyaniline films [a, as deposited; and b, HCl doped]

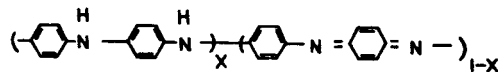


Fig. 16—The structure of vacuum deposited polyaniline film

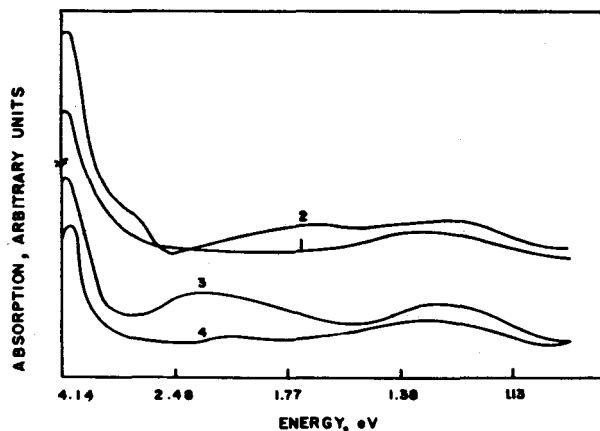


Fig. 17—Optical absorption of polyaniline film in the wavelength range 300-1000 nm and the effect of exposure to various environment [1, as deposited; 2, after exposure to air; 3, after exposure to ammonia; and 4, after exposure to HCl]

Table 3—Electronic parameters for vacuum deposited metal/polyaniline/Schottky device

Metal	Work function ϕ_m (eV)	Barrier height ϕ_b (V)	Ideality factor n
In	4.12	0.56	1.6
Sn	4.11	0.59	2.12
Pb	4.02	0.56	2.36
Al	3.74	0.55	1.20
Sb	4.05	0.55	4.50
Ag	4.28	ohmic behaviour	—

ergy band gap (2.14 eV). The characteristic peaks in the FTIR spectra correspond to the polymer backbone of polyaniline (Fig. 16). The optical absorption spectra in the range 400-1000 nm is shown in Fig. 17, which also shows the effect of various gases on the optical absorption of the polymer films. This is promising from the viewpoint of fabricating an optical gas sensor.

Comparison of $V-I$ characteristics (Fig. 18) and electronic parameters (Table 3) of the all vacuum deposited metal/polymer/metal configuration with those for polypyrrole and polyaniline shows that the vacuum prepared Al/polyaniline/metal structure makes an excellent rectifying contact and is ideal for device fabrication.

Space charge studies

When the semiconducting polymer is introduced between two blocking electrodes and elec-

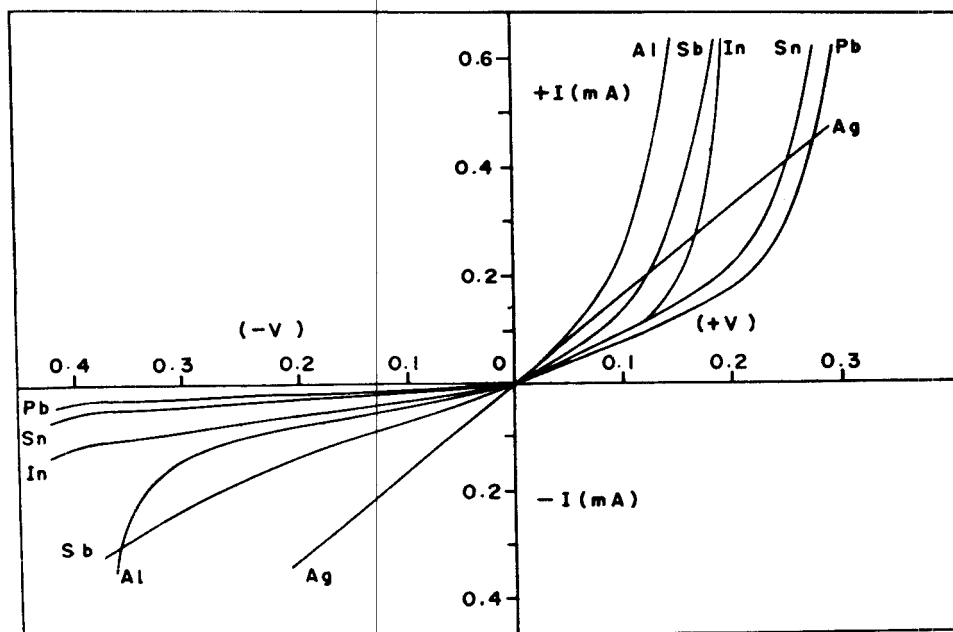


Fig. 18— V - I characteristics of all vacuum deposited metal/polyaniline/metal junctions with various metal electrodes, [Ag as the other electrode]

tric field is applied, it is possible to obtain space charge conditions, nonlinear behaviour, supralinearity, etc. Interfacial polarization, and the corresponding dielectric relaxation have potential in the preparation of charge coupled devices, frequency modulation, etc.²¹

Device fabrication

The results of studies on semiconducting polymers are used in fabrication of the following electronic devices: (i) two electrode metal/polymer system (for Schottky diodes and gas sensors), (ii) three electrode systems (for transistors), (iii) electroluminescent displays, and (iv) photovoltaic solar cells.

The Schottky diodes and gas sensors have been discussed above. After proper encapsulation they can be straightaway used for application. The three electrodes configuration made from conducting polymers for transistor application are being studied.

Polymeric electroluminescent devices

Another important use of semiconducting polymers is as electroluminescent devices^{13,13,25-29}. These devices use the metal/polymer contact as one of the injecting electrodes and the other as ohmic contact. The schematic diagram of a metal polymer electroluminescent device is shown in Fig. 19. The injection of electrons from metal into polymer creates negative polarons due to self lo-

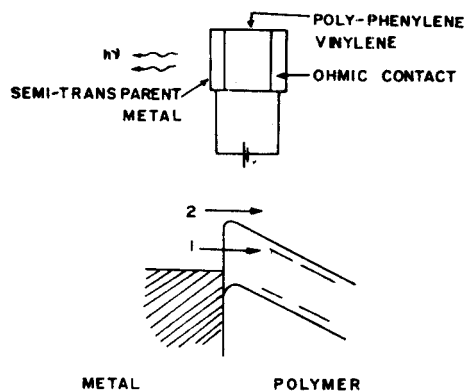


Fig. 19—The energy band diagram of the polymeric semiconductor based electroluminescent device. [1, injection of electrons from metal into polymer; and 2, injection of electrons in the polymer by tunnelling]

calization, which recombine with positive polarons to form the excited state of neutral bipolarons, the excitons. This entity then decays to emit radiation. The electrons may also be injected into semiconducting polymers by thermionic emission or by tunnelling into gap states followed by decay by radiative emission. Polyparaphenylene-vinylene (PPV) is the most sought after polymer for this purpose. Flexible light emitting devices have been fabricated using poly 2-methoxy-5(2'-ethylhexoxy)-1,4-phenylene-vinylene (MEH-PPV) with one Schottky and the other ohmic contact with a quantum efficiency of about 1%. It is essential to

create suitable conditions within the polymer by matching the interface characteristics and work function so that it can act as an electroluminescent device. Hence, it is very important to have a detailed knowledge of the energy band gap, optical absorption edge, gap states and *I-V* and *C-V* characteristics of the polymer. We have observed electroluminescence in polyaniline thin films. The vacuum evaporated films have been observed to exhibit photoconductivity, electrochromic effect and electroluminescence. The advantages of polymer based light emitting devices are the possibility of use in large area displays, ease of fabrication and flexibility. Cost effectiveness of such devices is another important advantage.

Polymeric photovoltaic devices

The following configuration can be envisaged for photovoltaic applications: (i) conducting polymer being used as metal in conjunction with inorganic semiconductor e.g. polypyrrole/on Si, (ii) semiconducting polymers being used as the p-type material on which a metal is deposited, forming the Schottky configuration, (iii) heterojunction formed at the interface between undoped polymer and inorganic semiconductor, and, (iv) fabrication of p-n junction on the same polymer by suitable doping-undoping.

It is not possible to prepare p-n junction of minority carrier based (like inorganic semiconductors) photovoltaic devices from semiconducting conjugated polymers, as most of them are p-type, and homo and graded p-n junction cannot be

created easily on the same specimen. The only alternative is to look for a Schottky barrier type polymeric photovoltaic device (Fig. 20) made on a heterojunction of semiconducting polymer with suitable metals. A transparent metal film having a work function (ϕ_m) lower than that of the polymer (ϕ_s) on which it is deposited serves as the front electrode. The back contact is made by depositing an ohmic contact on the polymer. A space charge is built up at the interface. When the radiation falls on the transparent side of the front (rectifying, Schottky) contact, positive and negative charges (electron-hole pairs) within the depletion region are created. These electron hole pairs are separated by the electric field in the junction present due to dissimilar work function and Fermi level. These electrons and holes give rise to photovoltage and photocurrent.

The requisites of a polymer based photovoltaic device are; high quantum efficiency for electron hole pair generation, large barrier height (χ_b), large absorption coefficient over a wide range of incident radiation and good electronic conductivity of polymer to conduct photogenerated charge.

The open circuit voltage from a polymer-photovoltaic device is given by

$$V_{oc} = \left[\frac{nkT}{e} \ln \frac{J_{sc}}{A^*T^2} + \frac{n\chi_b}{e} \right]$$

where J_{sc} is diode reverse saturation current or short circuit current, and χ_b is barrier height.

The fill factor is given by

$$F.F. = \frac{J_{mp} \cdot V_{mp}}{J_{sc} V_{oc}}$$

where J_{mp} and V_{mp} are the points for maximum power in *I-V* characteristics of the photovoltaic device under illumination.

The efficiency of the photovoltaic device is given by

$$\eta = \frac{J_{mp} \cdot V_{mp}}{P_{in}}$$

where P_{in} is the input power (radiation).

Various configurations of metal-polymer, and polymer-inorganic semiconductors have been tried but probably due to lack of a clean electronic contact at the polymeric interface, and also owing to the incomplete understanding of the complex phenomena of electrical conduction-optical absorption and photogeneration behaviour of

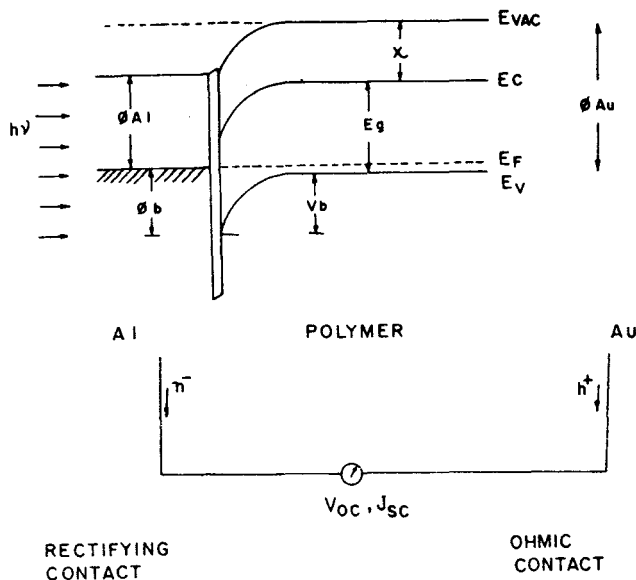


Fig. 20—Schematic diagram of a polymeric semiconductor based photovoltaic device

the polymers and their interfaces, it has not been possible to achieve a reasonable photovoltaic conversion efficiency and a large fill factor²⁹⁻³².

Application of electronic polymers in surface mount technology and devices

Recent advances in electronic component technology have revolutionized the industrial scene towards miniaturization and microminiaturization, which is essential to make an electronic device (whole package) cost effective, efficient and easily deployable at critical sites³³⁻³⁵. This has led to the development and production of a wide range of portable equipments like liquid crystal displays, televisions, photo-electronic, computing and communication equipments, etc. The introduction of newer technologies like tape automated bonding and large scale integration using multichip modules has led to higher packaging densities. Surface mount technology requires the development of surface mountable devices, encapsulation, their mounting adhesives and soldering and bonding at the printed circuit boards. Integrated optics (IO) is an example of surface mount device, where a polymer electronic light emitting device can be straightway fabricated on an optical polymeric fibre, and a polymeric photodetector can be fabricated at the end of the optical fibre. Electronic active elements like capacitors, resistors, inductors and conducting paths can also be made from polymeric materials like polypyrrole, polyaniline, polythiophene and polypropylene sulphide after suitable modification of the fabrication process to achieve specific requirements. From this point of view the environmental stability of the polymers is also to be studied. Polyaniline, polypyrrole and polythiophene have been found to be quite stable polymers. The other promising application of conducting polymers is their use in fabrication of double-sided, single-sided and multilayer bonded plated through hole printed circuit boards. Polyaniline conductors are used to precoat the insulating board to provide a sensitised surface for Cu electroplating. The polymer replaces the electrode's Cu coating which involves use of toxic formaldehyde, reductants and expensive palladium salts. Use of conductive polyaniline is inexpensive, and environmentally friendly. Polymers find use in printed wire board technology as epoxy bonding materials, flexible adhesive films, polyamide, reinforced organics, laminated teflon dielectric encapsulants, passivators and multilayer polymer on metal (four channel) molded microwave stripline flex. The materials suitable for such applications are triazene resin, kevlar (Aramid)

and PTFE. The choice of the material depends upon the specific application, thermal and electrical properties being important factors. Encapsulation of these electronic devices and passivation of the printed circuit board is an area where high quality of stable polymer, resistant to environmental conditions, temperature, humidity and radiation are required. Very often in opto-electronics and photovoltaic devices and other electronic equipments the encapsulant should have a specific transparency in the given radiation wavelength range. Ethylene-vinyl acetate (EVA) is the polymeric encapsulant used in photovoltaic modules and provides structural support, electrical isolation, physical isolation, protection and thermal conduction for photovoltaic devices³⁶. The composition of ethylene vinyl acetate copolymer ranges from 3-33% vinyl acetate. The 33% vinyl acetate copolymer is excellent for photovoltaic device encapsulation due to its transparency over a wide spectrum and long term stability under different environments. The general characteristics of ethylene vinyl acetate are given in Table 4.

The vacuum deposited and solution cast films of ethylene vinyl acetate have been studied for their electrical properties. It has been observed that EVA films having a thickness of the order of 1000 Å have good dielectric strength and can withstand a field of the order of 10^8 V/m. Above this, a Schottky behaviour is observed. EVA is a polymer which can be easily processed and made into films cost effectively. For high field applications, a negative differential resistance is observed in EVA films³⁷.

Another important aspect of surface mount technology is to provide footprint design and solderability. The objective of the footprint design is to achieve a high packing density for components and routing of interconnecting tracks, and also promote maximum yield and cost effectiveness. A

Table 4—Characteristics of electronic quality ethylene vinyl acetate copolymer

Parameter	Value
Specific gravity	0.93
Yield strength	1.3 kg/cm ²
Tension modulus	11 kg/cm ²
Form of fracture	Tough
Viscal softening	83
ASTM brittleness	-70°C
Power factor at 100 Hz	0.0024
Dielectric constant	2.8

footprint design may be made out of soft pads on which a device can be placed and then solderable connections can be taken out from them. These are known as pads. The basic requirements of pads in surface mount technology are: (i) optimum length and width of the pads to prevent the component from sliding and rotating, (ii) optimum surface tension of the solder, (iii) minimum thickness from a pad to an adjacent via should be less than 3 times the track thickness to prevent solder paste from running down into via and forming a solder bridge, and, (iv) vibration absorbent mechanical dampers.

The thermal properties are also of importance in designing the pads as there are a number of devices which require fast dissipation of heat to the printed circuit board. Polymeric composites like carbon reinforced silicon rubbers provide an alternative to the present day surface mount device pads. The micro dots prepared from carbon reinforced silicon rubbers have a wide range of mechanical properties and electrical conductivity. The conductivity is provided by carbon and the softness and mechanical damping of vibration by polymer silicon. High electric conduction, and the capacity to dampen the mechanical vibration is exhibited by these carbon silicon rubber composites. The hardness of these composites is in the range of 50-80, and density, of the order of 4.07 gm/cc. Conductivity up to the range of 100 S/cm could be achieved in these composites. These polymer composites can be commercially produced for a large production line of surface mount devices. It has been observed that polyaniline is a good alternative to carbon for these applications due its environmental and chemical stability.

Other electronic applications of semiconducting polymers include microwave absorbers for use in microwave and EMI shielding and military applications, temperature sensors and capacitors³⁸⁻⁴⁶. Various configurations of the device structures like metal/polymers, polymer/inorganic semiconductor/two layers of polymeric semiconductor in contact with C₆₀, etc., have been investigated for use as electronic components for a variety of applications including electro-optical and frequency modulation devices³⁹⁻⁵⁰.

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